

# SENSORY INFORMATION FROM AFFERENT NEURONS

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## PROGRESS REPORT #5

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NEURAL PROSTHESIS PROGRAM.**

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## I. Objectives of Overall Project

Our aim is to develop and perfect, in an animal model, methods for chronic recording and processing of afferent activity produced by sensory receptors that could yield information about human fingertip contact, grasped object slip, finger position, and grasp force applicable for restoration of motor functions in the paralyzed human hand. The specified contract objectives are:

1. Select recording methods that:
  - a. Have the potential of providing safe, reliable recordings in humans for periods of years.
  - b. When used in human applications, could provide relatively isolated information from the sensory endings in the thumb pad and in the finger pads of the second and third fingers.
  - c. Could, in human applications, provide information from the proprioceptive receptors in the muscles of the hand and wrist.
2. Select an animal model suitable for chronic recording of afferent nerve activity, and give consideration to modeling electrode placement sites for a potential human neural prosthesis application.
3. Fabricate or obtain chronic electrodes and associated cables and percutaneous connectors for chronic recording of sensory afferent activity.
  - a. Design electrodes and cables using biocompatible materials that would be suitable for potential future human implants.
  - b. Design electrodes and cables with the goal of producing a chronic implant that causes minimal nerve damage.
4. Investigate the possibility of extracting information about contact, grasped object slip, limb position and contact force from chronically recorded neural activity using the animal model and electrodes from parts 2 and 3.
  - a. Devise recording, processing, and detection methods to extract this information from recorded neural activity in a restrained animal.
  - b. Modify these methods as needed to function in an unrestrained animal and in the presence of stimulation artifacts associated with functional electrical stimulation.
  - c. Record activity for periods of at least 6 months and devise functional measures to track any change in neural response over this time.
  - d. Evaluate any histological changes in the nerves that occurred over the period of chronic recording and, if possible, correlate these changes to changes in functional response.
5. Cooperate with other investigators in the Neural Prosthesis Program by collaboration and sharing of experimental findings.

## II. Summary of Progress in the Fifth Period

During the fifth reporting period we completed the study of 5 animals that were chronically implanted, for periods ranging between 8 and 12 months, with either Multi-Contact Cuffs (MCCs--3 animals) or Longitudinal Intra-Fascicular Electrodes (LIFEs--2 animals). We monitored compound action potentials, device impedances and trends in multi-channel recording selectivity using electrical stimulation of the digits under gas anesthesia, and we recorded multi-channel nerve and muscle activity during treadmill walking. On the final day for each animal, we obtained final CAP data for each implanted nerve. We also performed acute recordings under deep anesthesia from the median, ulnar and radial nerves in the contralateral limb above the elbow, to investigate the feasibility of recording multichannel nerve activity at a more proximal location where several sources of proprioceptive afferent activity arising from elbow, wrist and digit areas are available. At the end of the acute experiment, we removed histological samples from the chronically cuffed nerves and the contralateral control nerves.

During this period, a new group of cats was trained to walk on the treadmill and to reach and grasp a computer-controlled joystick with the left forelimb. One cat was implanted with LIFEs in the median, ulnar and radial nerves above the elbow. The other cats were scheduled for surgical implantations early in the Sixth Period.

## III. Details of Progress in the Fifth Period

### A. Completion of Long-term Recordings from Six Cats

In our previous progress reports we described two basic multi-channel approaches that we are investigating in parallel for this contracted research, **multi-contact cuffs (MCCs)** and **longitudinal intra-fascicular electrodes (LIFEs)**. In Yr 1 we implanted two arrays of either one type or the other type, in the left forelimb of each of three cats. A total of six cats were studied for periods ranging between 7 and 12 months (NIH 18 - NIH 23). NIH 22 was sacrificed during the Fourth Period. During the Fifth Period we completed the study of the remaining five cats.

In all these cats, the arrays were placed on the median and ulnar nerves distal to the elbow. The dominant neural activity in the cuffed nerves was of sensory origin, mainly arising from the digits and paw. We investigated the selectivity of the electrode arrays with respect to identification of which of the five digits was stimulated, using either mechanical or electrical stimulation. It was clear that the

majority of the active nerve fibers that were recorded were sensory fibers, and that most of these were of cutaneous origin.

Detailed information about electrode design and the recording selectivity of nerve electrode arrays, as well as the physiological findings from these long-term studies, are being prepared for publication at this time.

## **B. Morphological Analysis of Cuffed Peripheral Nerves**

During the final acute experiment, each animal was maintained in a deeply anesthetized state with halothane. We removed histological samples of the median and ulnar nerves of the three cats that had been implanted with multi-contact nerve cuffs for periods of 8-12 months. We also removed samples of the contralateral nerves, which had not been chronically implanted and are expected to serve as controls.

For one animal, several 2-4 mm long nerve samples were removed and placed in fixative. The other two animals were perfused with fixative through a cannula placed in the heart before the nerve samples were removed and placed in fixative. We used the fixative recipes described in our previous Progress Reports.

Histological examination of these tissues, including morphometry, is planned to be carried out during the Sixth Period.

## **C. Multi-Channel Recordings from Proximal Forelimb Nerves**

The motor nerve branches that innervate the wrist, paw and extrinsic digit muscles split off from the parent nerves at the level of the elbow or just below the elbow. Thus, these nerve branches were not present in the ulnar and median nerves at the level where the electrodes were placed in NIH 18 - NIH 23.

Proprioceptive afferent information associated with forelimb movements during walking, reaching and manipulating a joystick, is expected to be available in the median, ulnar and radial nerve trunks above the elbow. We decided to explore the possibility of implanting multi-contact nerve electrode arrays (cuffs or LIFEs) on these nerves, above the elbow.

The median, ulnar, radial and distal musculocutaneous nerves run together with the brachial artery and brachial vein in the proximal region of the forelimb, parallel to the humerus. In mature male cats, these nerves can be surgically exposed through a medial incision between triceps and biceps, and can be dissected free from surrounding connective tissues over a length of 15-20 mm. More proximally, surgical access becomes difficult because of the location of chest

muscles that cannot be further retracted without risk of damage; and in any event, the nerves branch and are reconfigured into cervical roots in the brachial plexus region. More distally to the selected site, the radial nerve takes a separate route from the median and ulnar nerves, and changes its course in a lateral direction.

On the days that the final acute experiments were performed on NIH 18-23, we also explored the feasibility of placing cuff electrode arrays around the ulnar, median, radial and musculocutaneous nerves in the proximal forelimb region. This approach was tried in the right (unimplanted) limbs and, though surgically challenging, proved feasible. Acute experimental recordings suggested that a broad variety of sensory sources could be clearly distinguished using multi-channel nerve cuffs placed in this proximal location. Sensory fields included several proprioceptive as well as cutaneous modalities. On the basis of these acute experimental results, we decided to implant electrode arrays in the proximal forelimb in the next series of cats.

The first cat in this new series was implanted in December, 1997 and received eight pairs of LIFEs, which were installed by Dr. Yoshida as part of our ongoing collaboration. The LIFEs were implanted in the upper forelimb region and were distributed among the median, ulnar and radial nerves. Each of the median, ulnar and radial nerves received a single-channel recording cuff implanted below the elbow, and EMG electrodes were implanted on six distal limb muscles, as well as on Triceps and Biceps.

## IV. Plans for the Sixth Period

During the sixth reporting period, from January 1, 1998 to March 31, 1997, our objectives will consist of the following:

We will implant four more animals in addition to the one already implanted as part of the second series of implants for this contract.

We will follow the performance of electrodes and nerves for 180 days in each animal.

We will record from these animals during the performance of forelimb reaching movements using the protocol communicated by Hansen et al., 1997 (1). We will record multichannel ENG's as well as EMG's from six muscles during performance of reaching movements.

We will analyze data collected during walking on the treadmill and the multi-channel ENG data from the LIFEs and from the MCCs will be evaluated to determine if differences in the signals (and thus the selectivity) can be detected and to determine the reliability and utility of these signals.

We will continue the collaboration with Drs. Yoshida and Stein represented by the implantation of two animals with LIFEs and subsequent data analysis.

We will continue with the collaboration with Dr. Andrews by collecting and analyzing data from the MCCs and virtual sensors.

## V. Publications and Meetings

### A. Meetings attended During the Fifth Period

October 15, 1997: Andy Hoffer, Kevin Strange and Ken Yoshida attended the 28th. Annual Neural Prosthesis Workshop in Bethesda, MD. The report on progress was based on a PowerPoint presentation and generated lively discussion about some of the new results that were presented.

November 15, 1997: Dr. Hoffer attended the 6th. Annual Meeting of the Japan F.E.S. Association in Osaka, Japan, where he gave an invited 90-minute Keynote presentation, titled "Sensory Nerve Signals Recorded from Paralyzed Limbs: Applications for Control of FES."

November 17, 1997: Dr. Hoffer gave an invited 2-hour presentation at the Department of Therapeutics & Rehabilitation Sciences, Institute for Developmental Research, Aichi Prefecture, Nagoya, Japan.

December 23, 1997: Dr. Hoffer gave an invited 60-minute presentation to neuroscientists and electrical engineers at the Instituto de Ciencias Biológicas Clemente Estable, Montevideo, Uruguay, titled "*Métodos Multicanales de Registro en Nervios Sensoriales: Aplicación Para el Control de Estimulación Eléctrica de Músculos Paralizados.*"

## VI. Reference

- [1] Hansen, M., K.D. Strange, Y. Chen and J.A. Hoffer, "Sensory Feedback for Control of Reaching and Grasping Using Functional Electrical Stimulation" Proc. 2nd. IFESS Conf., 1997, pp 253-254.